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Expert Water Quality Panel Review of Responses to the NASA Request for Information for the International Space Station On-Board Environmental Monitoring System

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Contents page

Tables page

Appendices page

List of Acronyms

AEMC	Advanced Environmental Monitoring and Control
BTEX	Benzene, Toluene, Ethylbenzene, and Xylene
CHeCS	Crew Health Care System
COTS	Commercial Off-The-Shelf
C-SPE	Colorimetric - Solid Phase Extraction
D	Demonstrated
Env	Environment
EVS	Evanescent Spectrometer
GC	Gas Chromatography
GC/MS	Gas Chromatography/Mass Spectrometry
IC	Ion Chromatograph
IMS	Ion Mobility Spectrometer
ISS	International Space Station
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
LN2	Liquid Nitrogen
MS	Mass Spectrometry
NASA	National Aeronautics and Space Administration
NH3M	Ammonia Monitor
OAAM	Organic Acid and Alcohol Monitor
ORU	Orbital Replaceable Unit
OSU	Oklahoma State University
P	Potential
RFI	Request for Information
TOCA	Total Organic Carbon Analyzer
TRL	Technology Readiness Level
UV-vis	Ultraviolet-visible
VOA	Volatile Organics Analyzer
VOLTA	Voltammetry
WAFAL	Water and Food Analytical Laboratory
WF	Weighting Factor

ABSTRACT

On August 9, 2003, NASA, with the cooperative support of the Vehicle Office of the International Space Station Program, the Advanced Human Support Technology Program, and the Johnson Space Center Habitability and Environmental Factors Office released a Request for Information, or RFI, to identify next-generation environmental monitoring systems that have demonstrated ability or the potential to meet defined requirements for monitoring air and water quality onboard the International Space Station. This report summarizes the review and analysis of the proposed solutions submitted to meet the water quality monitoring requirements. Proposals were to improve upon the functionality of the existing Space Station Total Organic Carbon Analyzer (TOCA) and monitor additional contaminants in water samples. The TOCA is responsible for in-flight measurement of total organic carbon, total inorganic carbon, total carbon, pH, and conductivity in the Space Station potable water supplies. The current TOCA requires hazardous reagents to accomplish the carbon analyses. NASA is using the request for information process to investigate new technologies that may improve upon existing capabilities, as well as reduce or eliminate the need for hazardous reagents. Ideally, a replacement for the TOCA would be deployed in conjunction with the delivery of the Node 3 water recovery system currently scheduled for November 2007.

EXECUTIVE SUMMARY

Proposed systems and component technologies for ISS on-board environmental monitoring were to meet several technical requirements in addition to measuring a prioritized set of parameters. A brief summary of requirements and goals is provided below.

Technical Requirements

The replacement system should:

- Fit the current Volatile Organic Analyzer (VOA) footprint within the Crew Health Care System rack
- Detect and quantify a significant percentage of identified contaminants and compounds
- Operate in a spacecraft environment in a possibly highly contaminated atmosphere
- Demonstrate specific instrumental characteristics - linearity, analysis time, analysis cycle time, mass, volume, power requirements, calibration and maintenance cycles, and consumable resources

Prioritized Goals

Chosen approach will provide the best combination of value and meeting the following prioritized goals:

- Eliminate or reduce of the use of hazardous substances (such as toxic reagents)
- Minimize logistics costs – initial launch and resupply
- Improve contaminant detection and quantification with respect to current instrumentation
- Decrease volume and mass properties into a single footprint (33.5 x 19 x 10.5 in.)

Review Panel Approach

NASA received eight responses to the water portion of the Request for Information (RFI). An 11-member panel consisting of eight external experts and 3 JSC/NASA relevancy experts from Environmental Factors, Safety and Mission Assurance, and the Water and Food Analytical Laboratory (WAFAL) met on October 22 & 23, 2003 to review and score the water-only submittals and the water portion of the combined air-water system submittals. Presentations made by representatives of each entity that submitted a response to the RFI were followed by question-and-answer sessions and then panel deliberations. A technology assessment metric sheet for rating specific aspects of each technology on a 4-point system was used for scoring the presentations. Individual characteristics and/or system requirements scores were combined into the following 5 areas: operation in a spacecraft environment; instrument characteristics; system characteristics; compounds; and instrument maintainability. Both "demonstrated" and "potential" system performance were scored.

After completion of the review, members of the panel completed the following questionnaire:

- Which team has the best concept and chance of success for monitoring organics?
- Which team has the best concept and chance of success for monitoring inorganics?
- Overall, which team could best monitor both the organics and inorganics?
- Are any concepts appropriate for short-term (0-2 years) implementation?
- Which concepts are appropriate for the mid-term (2-5 years)?
- Which are best mid-term and long-term (>5 years) technologies for inorganics: voltammetry/electrodes, reagentless ion chromatography, colorimetric solid phase extraction,

or the porphyrin optical sensor?

- Which seems best for NASA to pursue for specific organics: gas chromatography/mass spectrometry or ion mobility spectrometry, or other? Why?
- Is it practical to develop a single instrument for both air and water analysis?
- Is it practical to integrate water inorganic and organic analyses in a single package?
- If you could, how would you mix and match team elements for best chance of success? Rank your matches. Indicate short-, mid-, or long-term solution potential, if known.
- Discuss advantages/disadvantages, strength/weakness of teams/concepts as presented.

Results

Table 1 presents the area scores and final weighted score for each of the presenters/vendors that submitted a water-related proposal in response to the RFI. Although panel members were highly discriminating in their scoring, small differences in scores between two vendors does not necessarily mean that one proposal is clearly superior to the other.

Table 1
Demonstrated/Potential Scores

Parameter/ Vendor	OI Analytical	Smiths Detection	JPL-Thorleaf	Star	Umpqua	OSU	Lynntech, Inc.
Operation in spacecraft environment	10/15	10/14	12/15	11/16	11/14	10/14	10/15
Instrument characteristics	5/18	5/18	12/20	9/17	10/19	20/20	18/20
System characteristics (Double Weighting)	15/21	19/23	19/24	14/21	10/17	19/28	15/19
Compounds (Double Weighting)	12/34	16/34	18/30	16/34	30/34	20/36	10/38
Instrument maintainability	3/7	3/11	12/12	3/10	3/8	10/12	3/11
Total Score: Demonstrated/ Potential	45/95	53/100	73/101	53/98	64/92	79/110	56/103

Conclusions

None of the water quality proposals was strong in detecting both organic and inorganic contaminants.

A system that meets all the water quality monitoring requirements can be developed most rapidly by selecting the best technology for each category of contaminants and subcontracting accordingly with NASA acting as system integrator.

NASA should not limit itself to only those vendors that responded to the RFI during its decision-making process. There are research groups developing water quality monitors that did not respond to the RFI.

For short-term (0–2 years) monitoring of organics in the water, there was no clear consensus on an approach that would be better than the TOCA currently being used.

For monitoring specific organics over the mid- (2-5 years) to long-term (>5 years), the consensus was GC/MS technology is better than GC-IMS technology due to its capability to handle unknowns. There was no consensus on which GC/MS system was the best, suggesting such a system should be procured by competitive procurement.

For short- to mid-term monitoring of inorganics, there was consensus that the Iowa State University C-SPE approach appears to be the only concept that can be implemented quickly, despite its weaknesses.

For mid- to long-term monitoring of inorganics, there was no consensus on the best approach. All of them have weaknesses. The three concepts that appear to warrant further investigation are the Oklahoma State University porphyrin evanescent spectroscopy, reagentless IC, and electrode/voltammetry technologies.

Concerning integration of monitoring systems, the panel was unanimous that there was little to be gained by integrating air and water quality monitors into a single package.

The panel unanimously concluded there was little to gain by combining the organic and inorganic analyses for water quality contaminants into a single package.

INTRODUCTION

Monitoring of water pollutants is critical to ensuring the health of crews aboard the Space Station and, ultimately, to mission success. However, monitoring Space Station water supplies poses numerous technical challenges for the hardware provider. These include hardware size limitations, restrictions on the use of potentially hazardous reagents, microgravity considerations, the overall remoteness of the monitoring operations, and other factors unique to the spacecraft environment.

To help address these challenges, the Vehicle Office of the International Space Station Program and the Advanced Human Support Technology Program released a Request for Information (RFI) on August 9, 2003. The purpose of this RFI was to seek out new technologies and solutions that can address these technical challenges and, perhaps, help provide the next generation Space Station water quality analyzer. NASA currently has an orbital replaceable unit onboard the Space Station in the form of the Total Organic Carbon Analyzer (TOCA). The TOCA is designed to measure total organic carbon, total inorganic carbon, total carbon, pH, and conductivity in water samples. In the RFI responses, NASA hoped to identify new technologies and/or strategies that can build upon the existing capabilities of the TOCA and provide an improved tool for reliably monitoring the quality of the Space Station water supplies. The RFI described the on-board TOCA and provided information on water quality monitoring system requirements for vendors interested in responding. These requirements included:

- Fitting the current Volatile Organic Analyzer (VOA) footprint within the Crew Health Care System (CHeCS) rack.
- Detecting and quantifying a significant percentage of identified compounds of concern
- Operating within a spacecraft environment in a possibly contaminated atmosphere
- Demonstrating specified instrument characteristics and maintenance properties, such as linearity, analysis time, and required calibration intervals

In addition, the RFI also listed the following four prioritized goals for the development of a TOCA replacement system:

- Eliminating or reducing the use of hazardous substances
- Minimizing logistics costs
- Improving contaminant detection and quantification
- Decreasing volume and mass properties into a 33.5 x 19 x 10.5 in. footprint

Aiding the assessment of suitable instrument concepts, team members developed prioritized lists of organic and inorganic contaminants of concern in Space Station water supplies (see Tables 2 and 3).

NASA received eight submissions to the RFI that included water quality monitoring (five combined air-water systems and three water-only systems). In October 2003, an 11-member panel of subject matter experts assembled to review information submitted in the water-related RFI responses. Eight of the panelists were external to NASA, while the remainder represented internal JSC/NASA experts from different program areas—environmental factors, safety and mission assurance, and the Water and Food Analytical Laboratory (WAFAL). This water quality panel was asked to provide a critical review and feedback to NASA/JSC on the merits of the proposed water monitoring systems. This document is intended to describe the methodology applied by the panel in its analysis and present the panel results and recommendations. It should be noted that a similar panel convened to address air monitoring aboard the Space Station and this was also a focus of the RFI. Although some presenters responded to the RFI with joint air and water monitoring proposals, the discussion presented in this document is specific only to the water sections of any joint proposal.

STRUCTURE OF THE PANEL REVIEW

The charge to the water quality panel was to review and evaluate the RFI responses for water monitoring systems and to rate those systems in terms of their ability to meet the requirements and prioritized goals for the next-generation Space Station water quality analyzer. Before the water quality panel review meeting, the submitters provided an abstract or other preliminary information as required in the RFI. This information was distributed and evaluated by the panelists before the meeting on October 22-23, 2003.

The water quality panel review meeting began with an overview presentation by the panel chair on the status of water quality monitoring aboard the Space Station and the NASA considerations and requirements that are pertinent to water monitoring. Over the course of two days, the responding presenters/vendors gave 45 minute presentations describing their proposed monitoring system (see schedule shown in Table 4). At the end of each presentation, panelists asked for additional information or necessary clarification. The panelists then scored the concept using a technology assessment metric (Table 5). This metric was a modified version of the tool used in the 1998 panel review of spacecraft air quality instrumentation. The panel scored each proposal based on specific system requirements within the general parameters of: (1) operations in spacecraft environment, (2) instrument characteristics, (3) system characteristics, (4) compounds, and (5) instrument maintainability. Each vendor scored in two categories: "Demonstrated" and "Potential". The first category is an assessment of what the proposer has already achieved and demonstrated for use in the short-term. The latter category is an assessment of what the proposed system might reasonably be able to achieve within certain conditions and/or modifications.

At the completion of the water quality panel review, each panelist received a water quality monitor rating discussion sheet to complete and return. They responded to the following questions:

- Which team has the best concept and chance of success for monitoring organics?
- Which team has the best concept and chance of success for monitoring inorganics?
- Overall, which team could best monitor both the organics and inorganics?
- Are any concepts appropriate for short-term (0-2 years) implementation?
- Which concepts are appropriate for the mid-term (2-5 years)?
- Which are best mid- and long-term (>5 years) technologies for inorganics: voltammetry/electrodes, reagentless ion chromatography, colorimetric solid phase extraction, or the porphyrin optical sensor?
- Which seems best for NASA to pursue for specific organics: gas chromatography/mass spectrometry or ion mobility spectrometry or other? Why?
- Is it practical to develop a single instrument for both air and water analysis?
- Is it practical to integrate water inorganic and organic analyses in a single package?
- If you could, how would you mix & match team elements for best chance of success? Rank your matches. Indicate short-, mid-, or long-term solution potential, if known.
- Discuss advantages/disadvantages, strength/weakness of teams/concepts as presented.

Table 2. Targeted Organic Compounds for Water Quality Monitoring

Parameter	Minimum Detection Limit, μg/L
Priority 1	
Total Organic Carbon (TOC)	500
Formate/Formic acid	500
Propylene Glycol (or Total glycols)	500
Ethanol (or Total alcohols)	500
Methanol (or Total alcohols)	500
Caprolactam	1500
Priority 2	
Acetate/Acetic Acid	200 *
Acetone	200 *
Isopropanol	200 *
Formaldehyde	100
Ethylene Glycol	1200
Glycerol	200 *
Propionic acid	200 *
Urea	200 *
Priority 3	
Phenol	100
Methyl ethyl ketone	400
2-Butoxyethanol	200 *
Chloroform	8
Methylene chloride	0.5
N-Butylbenzenesulfonamide	200 *
Benzothiazole	200 *
Dibutyl phthalate	400
Diethyl phthalate	3000
bis-2-Ethylhexylphthalate	0.6
Benzyl alcohol	200 *
1-Propanol	200 *
1-Butanol	200 *
Isopentanol	200 *
2-Ethoxyethanol	200 *
Acetaldehyde	200 *
Methylamine	200 *
Butyric acid	200 *
Valeric acid	200 *
Caproic acid	200 *

* Minimum Detection Limits have not been established. Assume 200 μg/L.

Table 3. Targeted Attributes & Inorganic Compounds for Water Quality Monitoring

Parameter	Minimum Detection Limit, µg/L
Priority 1	
Conductivity	-
pH	2 - 12
Silver	50
Lead	5
Nickel	10
Ammonia	200
Iodine	5
Priority 2	
Cadmium	0.5
Zinc	500
Fluoride	150
Chromium	10
Turbidity	0.15 NTU
Priority 3	
Arsenic	1
Barium	100
Calcium	10000
Chloride	25000
Copper	100
Cyanide	200*
Iron	30
Magnesium	5000
Manganese	5
Mercury	0.2
Nitrate	1000
Potassium	200*
Phosphate	200*
Sulfate	25000

* Minimum Detection Limits have not been established. Assume 200 µg/L.

Table 4. Agenda for Water Quality Panel Review and Listing of Presenting Vendors

Presentations for Combined Air-Water Instruments
October 22, 2003

OI Analytical	
8:30AM – 9:15AM	Presentation
9:15AM – 9:30AM	Question & Answer
9:30AM – 10:00AM	Panel Deliberation
Smiths Detection	
10:00AM – 10:45AM	Presentation
10:45AM – 11:00AM	Question & Answer
11:00AM – 11:30AM	Deliberation
JPL-Thorleaf	
1:00PM – 1:45PM	Presentation
1:45PM – 2:00PM	Question & Answer
2:00PM – 2:30PM	Deliberation
Boeing Team	
2:30PM – 3:15PM	Presentation
3:15PM – 3:30PM	Question & Answer
3:30PM – 4:00PM	Deliberation
Star Instruments	
4:00PM – 4:45PM	Presentation
4:45PM – 5:00PM	Question & Answer
5:00PM – 5:30PM	Deliberation

Table 4. Agenda for Water Quality Panel Review and Listing of Presenting Vendors, cont'd

Presentations for Water-Only Instruments
October 23, 2003

UMPQUA Research Co.

9:00AM – 9:45AM	Presentation
9:45AM – 10:00AM	Question & Answer
10:00AM – 10:30AM	Panel Deliberation

Oklahoma State University

10:30AM – 11:15AM	Presentation
11:15AM – 11:30AM	Question & Answer
11:30AM – 12:00N	Deliberation

Lynntech, Inc.

1:30PM – 2:15PM	Presentation
2:15PM – 2:30PM	Question & Answer
2:30PM – 3:00PM	Deliberation

Table 5. Technology Assessment Metric Utilized by the Water Quality Panel

This metric is a modified version of the tool used in the 1998 panel review of spacecraft air quality instrumentation.

Requirements Scale (except where noted)	
1	requirement not met, but meets 25-50% of requirement
2	requirement not met, but meets over 50% of requirement
3	requirement met
4	requirement exceeded

Parameter 1
Operation in Spacecraft Environment
Weighting factor= 1

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Temperature	65-85 °F (18-29 °C)			
Pressure	10.2-15.0 psia			
Microgravity compatible	Absolute requirement	Samples may contain 20% gas by volume	*	*
Ability to perform in highly contaminated samples				
Parameter Score				

*Microgravity compatible: Inherent microgravity compatibility demonstrated= 4, Gas-liquid Separators or inherent capability included, but not demonstrated= 3, Additional bubble removal from samples required= 2, Additional gas-liquid separators required= 1, Microgravity compatibility not addressed= 0

Parameter 2
Instrument Characteristics
Weighting factor= 1

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Analysis time	< 1 hr			
Analytical cycle time	<1.5 hr			
Mass	22 kg			
Volume	$3.9ft^3$ ($0.11m^3$)			
Power	<100 W/150W peak			
Parameter Score				

Table 5. Technology Assessment Metric Utilized by the Water Quality Panel Parameter, cont'd

Parameter 3
System Characteristics
Weighting factor= 1 or 2

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Maturity including software (WF= 2)			See key*	See key*
Reagents (WF= 2)			See key**	See key**
Environmental impact (WF= 1)	Contaminants not released to env		See key***	See key***
Complexity (WF= 2)			See key****	See key****
Parameter Score				

*Maturity: >TRL 8= 4, >TRL 6= 3, >TRL 4= 2, >TRL 2= 1, <TRL 2= 0

**Reagents: 0 reagents= 4, 1 reagent= 3, 2 reagents= 2, >2 resources= 1, exotic resources (i.e., LN2)= 0 (includes gases, other resources)

***Env.: No products released= 4, products released/not harmful= 3, Released products harmful to crew/systems= 0

****Complexity: < 3 modules= 4, < 5 modules= 3, <8 modules= 2, <10 modules= 1, >10 modules= 0

Parameter 4
Compounds
Weighting factor= 2

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
% Detectable Priority 1 parameters at specified limit			*	*
% Detectable Priority 2 & 3 parameters at specified limit			*	*
Quantitation range	0.1 to 100 times limit			
Specificity in spacecraft waters			**	**
Accuracy (6 mo)			***	***
Precision (over 1 month operation)			***	***
Parameter Score				

*% Compounds detected: >90% = 4, 75-90%= 3, 50-75%= 2, 25-50%= 1, <25%= 0

**Specificity: Demonstrated on actual samples= 4, demonstrated on synthetic waters= 3, partial mixtures tested= 2, interferences addressed= 1, specificity not addressed= 0

*** Accuracy: >90%= 4, >75%= 3, >50%= 2, Limited accuracy data= 1, no accuracy data= 0

Table 5. Technology Assessment Metric Utilized by the Water Quality Panel Parameter, cont'd

Parameter 5
Instrument Maintainability
Weighting factor= 1

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Calibration interval (quantitative purposes)	6 mo.			
Maintenance interval: minor major	 every 6 mo. > 1 yr.			
ORU's and Supplies	Every 6 months < 5 kg		See key*	See key*
Parameter Score				

* ORU/Supplies: > 6 mo/< 3 kg= 4, 6 mo/<5 kg= 3, 6 mo/> 5 kg= 2, < 6 mo/< 5 kg= 1, < 6 mo/> 5 kg= 0

RESULTS OF THE PANEL EVALUATION

Individual scores for both Demonstrated (D) and Potential (P) categories for each submittal are presented in Table 6. The table is organized in the order of the presentations. All individual total scores were summed after applying the designated weighting factors and are presented in Table 7. A ranking of presenters/vendors by D and P total scores is provided in Table 8. In Appendix 1, individual technology assessment metrics specific to each presenter/vendor are presented. All individual scores, along with applicable panel comments, are included in these assessment sheets. Appendix 2 contains presenter/vendor replies received in response to reviewing their individual technology assessment metrics results. The results of the evaluation of the Boeing team proposal are not included at their request.

Table 6. Summary of the Individual Parameter Scoring by the Water Quality Panel

Operations in Spacecraft Environment

Presenter/ Vendor	OI Analytical		Smiths Detection		JPL-Thorleaf		Star		Umpqua		OSU		Lynntech	
Analytical Methodology	GC/MS TOCA IC		GC-IMS VOLTA		GC/MS		GC TOCA		TOCA OAAM NH3M		EVS		TOCA IC	
	D	P	D	P	D	P	D	P	D	P	D	P	D	P
Temperature	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Pressure	3	4	4	4	4	4	3	4	4	4	4	4	4	4
Microgravity compatible	1	3	1	3	3	4	3	4	1	4	1	4	1	4
Ability to perform in highly contaminated samples	2	4	1	3	1	3	1	4	2	2	1	2	1	3

Instrument Characteristics

Presenter/ Vendor	OI Analytical		Smiths Detection		JPL-Thorleaf		Star		Umpqua		OSU		Lynntech	
Analytical Methodology	GC/MS TOCA IC		GC-IMS VOLTA		GC/MS		GC TOCA		TOCA OAAM NH3M		EVS		TOCA IC	
	D	P	D	P	D	P	D	P	D	P	D	P	D	P
Analysis time	1	3	1	4	1	4	3	4	4	4	4	4	4	4
Analytical cycle time	1	4	1	4	1	4	3	4	3	4	4	4	4	4
Mass	1	4	1	3	4	4	1	3	1	4	4	4	3	4
Volume	1	4	1	3	4	4	1	3	1	4	4	4	3	4
Power	1	3	1	4	2	4	1	3	1	3	4	4	4	4

Table 6. Summary of the Individual Parameter Scoring by the Water Quality Panel, cont'd

System Characteristics

Presenter/ Vendor	OI Analytical		Smiths Detection		JPL-Thorleaf		Star		Umpqua		OSU		Lynntech	
Analytical Methodology	GC/MS TOCA IC		GC-IMS VOLTA		GC/MS		GC TOCA		TOCA OAAM NH3M		EVS		TOCA IC	
	D	P	D	P	D	P	D	P	D	P	D	P	D	P
Maturity including software	2	4	2	4	3	4	2	4	2	4	1	4	2	4
Reagents	2	2	3	3	3	3	2	2	1	1	4	4	2	2
Environmental impact	3	3	3	3	3	4	2	3	2	3	3	4	3	3
Complexity	2	3	3	3	2	3	2	3	1	2	3	4	2	2

Compounds

Presenter/ Vendor	OI Analytical		Smiths Detection		JPL-Thorleaf		Star		Umpqua		OSU		Lynntech	
Analytical Methodology	GC/MS TOCA IC		GC-IMS VOLTA		GC/MS		GC TOCA		TOCA OAAM NH3M		EVS		TOCA IC	
	D	P	D	P	D	P	D	P	D	P	D	P	D	P
% Detectable Priority 1 compounds at specified limit	1	3	2	4	1	1	1	2	2	2	2	3	2	2
% Detectable Priority 2 and 3 compounds at specified limit	1	2	1	2	1	1	1	2	0	0	1	2	1	1
Quantitation range	1	2	1	4	3	4	1	3	3	4	1	4	0	4
Specificity in spacecraft waters	1	2	1	1	2	3	1	3	3	3	1	2	1	4
Accuracy (6 mo):	1	4	1	3	1	3	1	3	4	4	1	3	0	4
Precision (over 1 mo. opn):	1	4	2	3	1	3	3	4	3	4	4	4	1	4

Table 6. Summary of the Individual Parameter Scoring by the Water Quality Panel, cont'd

Instrument Maintainability

Presenter/ Vendor	OI Analytical		Smiths Detection		JPL-Thorleaf		Star		Umpqua		OSU		Lynntech	
Analytical Methodology	GC/MS TOCA IC		GC-IMS VOLTA		GC/MS		GC TOCA		TOCA OAAM NH3M		EVS		TOCA IC	
	D	**P**	**D**	**P**	**D**	**P**	**D**	**P**	**D**	**P**	**D**	**P**	**D**	**P**
Calibration interval (quantitative purposes)	1	2	1	4	4	4	1	3	1	2	2	4	1	3
Maintenance interval: minor - major	1	2	1	4	4	4	1	3	1	3	4	4	1	4
ORU's and supplies	1	3	1	3	4	4	1	4	1	3	4	4	1	4

Table 7. Summary of Individual Parameter Scores and Total Scores

Presenter/ Vendor	OI Analytical	Smiths Detection	JPL-Thorleaf	Star	Umpqua	Oklahoma State Univ.	Lynntech
Operation in Spacecraft Environment	10/15	10/14	12/15	11/16	11/14	10/14	10/15
Instrument Characteristics	5/18	5/18	12/20	9/17	10/19	20/20	18/20
System Characteristics (double weighting)	15/21	19/23	19/24	14/21	10/17	19/28	15/19
Compounds (double weighting)	12/34	16/34	18/30	16/34	30/34	20/36	10/38
Instrument Maintainability	3/7	3/11	12/12	3/10	3/8	10/12	3/11
Total Score: Demonstrated/Potential	**45/95**	**53/100**	**73/101**	**53/98**	**64/92**	**79/110**	**56/103**

Table 8. Presenter/Vendor Ranking by Total Score

	Presenter/Vendor	Demonstrated Total Score*
1	OSU	79
2	JPL-Thorleaf	73
3	Umpqua	64
4	Lynntech, Inc.	56
5	Smiths Detection	53
5	Star	53
7	OI Analytical	45

*maximum score=124

	Presenter/Vendor	Potential Total Score*
1	OSU	110
2	Lynntech	103
3	JPL-Thorleaf	101
4	Smiths Detection	100
5	Star	98
6	OI Analytical	95
7	Umpqua	92

*maximum score=124

DISCUSSION OF WATER SYSTEMS AND SCORES

Discussion of the results of the RFI response and the panel analysis scores is summarized in two parts in this report. First, the technologies proposed in the eight water-related responses and their strengths and weaknesses are summarized in the order presented to the panel. Second, the panel analysis scores for each system are discussed by scoring sheet parameter. The water quality panel made every effort to be fair in assigning individual scores; nevertheless, the scoring results are inherently semi-quantitative. Accordingly, it should be noted that a slight difference between the final scores for any two systems does not indicate that one system is clearly superior to the other.

PROPOSED WATER SYSTEM SUMMARIES

OI Analytical

The OI Analytical system for water quality monitoring incorporates gas chromatography (GC), ion chromatography (IC), and photocatalytic oxidation methods in a modular concept with a novel pump for gas-liquid separation. Specific organics are concentrated using solid-phase extraction then analyzed by GC with a detector array. Specific inorganics are analyzed by IC with a detector array. TOC is measured in a separate module using photocatalytic oxidation with infrared detection. Conductivity, pH, and turbidity are also analyzed using conventional techniques in the same module as the TOC. Water sample handling uses a gas-liquid separator pump concept. The system requires two non-hazardous reagents (carrier gas and a salt solution) for operation, excluding calibration standards.

The strengths of this proposal include a well thought-out concept for both organic and inorganic contaminants, previous experience with TOC and GC analyses, and the use of many off-the-shelf components. The weaknesses of this proposal include a complex system with many single-point failure modes, a pump separator that has not been demonstrated in microgravity, a lack of experience with trace metal detection by IC, and concerns over meeting the one-hour analysis time requirement.

Smiths Detection

The Smiths Detection system for water monitoring uses gas chromatography-ion mobility spectrometry (GC-IMS) for measurement of specific organics. Specific inorganics are measured using both voltammetry and ultraviolet/visible (UV-vis) light spectrometry. Conductivity, pH, and turbidity are analyzed using conventional methods in the same module where the optical measurements are made. The system does not directly measure TOC but suggests a surrogate measurement can be made using UV-vis spectrometry. A gas-liquid separator and pump is included and one non-hazardous reagent (nitrogen carrier gas) is needed. The GC-IMS design is to be based upon the microgravity-proven design of the Space Station VOA. The voltammetry block for measuring inorganics is only conceptual, however, and expertise in this area was not demonstrated.

JPL-Thorleaf

The JPL-Thorleaf team's system for water quality monitoring uses a miniaturized GC/MS to measure specific organics. The design of the proposed GC/MS system is to be based on the designs of GC and MS instruments that are already proven to be microgravity-compatible during previous NASA missions and appear to both have good dynamic range. The system does not measure anything other than specific organics, however, and requires helium as a carrier gas.

Boeing

The Boeing team requested the deletion from this report of system descriptions and all discussion related to the panel's evaluation of its proposal.

Star Instruments

The water monitoring system proposed by Star Instruments uses GC with a multiple detector array for analysis of specific organics and ultraviolet oxidation with infrared detection for TOC measurement. Conductivity and pH are also measured in the same module as TOC. The system requires two reagents (oxygen and GC carrier gases) for operation excluding calibration standards.

The strengths of this proposal are: Star's considerable NASA experience, a well-developed TOC system, and GC technology that is simpler than GC/MS or GC-IMS. The weaknesses of this proposal are that the system appears complex, specific inorganics are not included, and the GC technology is not as well developed for space flight as other proposed GC/MS or GC-IMS systems.

Umpqua

The water monitoring system proposed by Umpqua combines three different instruments—an organic acid and alcohol analyzer, an ammonia monitor, and a TOC analyzer—each using pH adjustment to generate volatile analytes that can be transferred from the water sample to a pure water stream by membrane separation and then measured by conductance detection. The combined system would provide capability to measure alcohols (ethanol, methanol, propanol, etc.), organic acids (formate, acetate, propionate), ammonia, ammonium, urea, nitrite, nitrate, TOC, inorganic carbon, pH, and conductivity. The combined system requires more than two reagents for operation, excluding calibration standards.

The strengths of this proposal are that Umpqua has already developed prototype instruments and has demonstrated the capability to measure most of the priority 1 contaminants.

The weaknesses of this proposal include the inability to detect most of the priority 2 and 3 contaminants, the inability to handle unknowns, the relatively large number of reagents and consumables required, and concerns that the membrane separators may be subject to interferences.

Oklahoma State University

The water monitoring system proposed by Oklahoma State University uses evanescent absorbance spectrometry to measure certain specific organic and inorganic compounds. This is accomplished by measuring changes in absorbance of an immobilized porphyrin thin-film. The strengths of this proposal are the simplicity and low weight and power requirements of the system and that the system does not require any reagents and needs no calibration. The weaknesses of this proposal include the undemonstrated capability to measure many specific organics and inorganics, concerns with the ability to analyze mixtures, and the lifetime of the porphyrin sensors.

Lynntech, Inc.

The water monitoring system proposed by Lynntech uses ion chromatography for separation and conduction for detection of specific inorganic contaminants (anions and cations) and photocatalytic oxidation with conductance detection for TOC measurement. The system requires two non-hazardous reagents (liquid salt and deionized water) for operation, excluding calibration standards.

The major strengths of the Lynntech proposal are the innovative solutions for minimizing reagents and waste and for miniaturizing the system. The TOC and liquid ion analyzer instruments are already in the breadboard phase and have been somewhat miniaturized. The weaknesses of this proposal include the complexity of the system, unclear reliability, and lack of capability to measure specific organics.

DISCUSSION OF SCORES BY EVALUATION PARAMETER

Operation in Spacecraft Environment

Within this parameter all 7 systems were judged able to demonstrate properly within the specified temperature and pressure ranges. Only 2 systems include technologies already proven to be microgravity compatible. Smiths Detection’s VOA-based GC/IMS technology has already been proven on Space Station. The JPL-Thorleaf miniature MS has also previously flown onboard the Space Station. The Star system was given a higher demonstrated score by the panel because the reagentless TOC analyzer was a part of the Process Control Water Quality Monitor protoflight unit. All 7 proposed systems are believed to have the potential to be microgravity compatible with additional development efforts.

None of the seven systems demonstrated the ability to meet the requirement of performing with “highly contaminated” samples. The data offered by some presenters was for pure samples only and the panel noted concern about the OSU system ability to handle mixtures. Possible interference across membranes with contaminated samples was also noted as a concern for the Umpqua system. Most systems were judged to have potential to meet this requirement given additional resources.

Instrument Characteristics

Four of the seven proposed systems—Star, Umpqua, OSU, and Lynntech—were judged to have already demonstrated the ability to meet or exceed given requirements for analysis and analytical cycle times, with the remaining teams—OI Analytical, Smiths Detection, and JPL-Thorleaf—showing potential to do so.

Several systems (OI Analytical, Smiths Detection, Star, and Umpqua) will need to overcome significant mass, volume, and power issues to be considered viable options for Space Station use, but review panel scores indicate some confidence in their potential to achieve required instrument characteristics in these areas.

System Characteristics

The JPL-Thorleaf GC/MS system is already at a technology readiness level of 6, while all other systems are in the range of 2 to 4. The panel scoring reflected that all systems have the potential to be developed into flight-certified hardware.

The OSU system was considered the only possible reagentless system, although it is unclear if the porphyrin sensors would require frequent replacement. Both the Smiths Detection and JPL-Thorleaf systems require the use of only one reagent or carrier gas each for operation, excluding calibration standards. The OI Analytical, Star, Umpqua, and Lynntech systems each require two or more reagents and/or carrier gases.

The panel determined that all seven systems should have no adverse impact on the Space Station environment. The panel, however, did note the lack of clarification of where the carrier gas would be vented for the JPL-Thorleaf system. The OI Analytical, Star, Umpqua, and Lynntech systems with TOC measurement provide acidification either by solid-phase or electrochemical methods that preclude the need for hazardous acid reagent. Nevertheless, these systems all generate an acidified sample stream that could potentially be hazardous. The panel gave lower demonstrated scores to the Star and Umpqua systems for not specifically addressing waste handling. The issue of disposition of used porphyrin thin-films for the OSU system was also noted as needing to be addressed further.

Six of the proposed water monitoring systems are estimated to comprise three to seven modules as demonstrated. Four of these are believed to have the potential to reduce to fewer modules in the final flight configuration. The Umpqua system requires eight or nine modules as demonstrated with potential to reduce to a 7-module configuration.

Compounds

The Smiths Detection, Umpqua, OSU, and Lynntech systems all demonstrated potential detection of 50-75% of Priority 1 compounds, while the OI Analytical, JPL-Thorleaf and Star systems detect 25-50% of these compounds at the specified limits. The systems proposed by OI Analytical, Smiths Detection, Star, and OSU were judged to have potential for significant improvement in detection of Priority 1 compounds with additional resources.

All seven proposed systems were able to identify and quantify between 0-50% of the Priority 2 and 3 compounds in Tables 2 and 3 at the specified limits. The systems proposed by OI Analytical, Smiths Detection, Star, and OSU were judged to have potential for significant improvement in detection of Priority 2 and 3 compounds with additional development efforts.

With regard to quantitation range, the JPL-Thorleaf and Umpqua systems were determined to be most able to meet the established requirement of three orders of magnitude. The panel gave lower demonstrated scores to all other systems because limited or no performance data was provided. All systems were scored as having the potential to meet this requirement given additional resources.

With respect to specificity in spacecraft water samples, the majority of the proposed systems did not adequately address interferences and were given low demonstrated scores by the panel. The exceptions were the Umpqua system that was tested with synthetic water and the JPL-Thorleaf system that was tested with partial mixtures. The panel scoring reflected potential for improvement in meeting this requirement by OI Analytical, JPL-Thorleaf, Star, OSU, and Lynntech systems.

Panel scoring reflected demonstrated accuracy over six months falls short on most all of the proposed systems due to limited or no accuracy data. The single exception to this was the Umpqua system that demonstrated better than 90% accuracy. All the other systems were scored as having the potential for much improved accuracy.

The panel gave the Star, Umpqua, and OSU systems higher scores for their demonstrated ability to meet precision requirements. All systems received potential scores that reflect the panel's confidence in their ability to meet this requirement with additional development.

Instrument Maintainability

The instrument maintainability parameter covers the following requirements: calibration at six-month intervals, minor maintenance intervals every six months, major maintenance intervals less frequently than once a year, and ORU's and supplies less then five kilograms every six months. The panel determined that the JPL-Thorleaf system meets or exceeds all requirements for this parameter. The OSU system was determined to meet or exceed all requirements except calibration. The panel scoring reflects the potential for improvement in meeting these requirements in the mature systems.

SUMMARY AND CONCLUSIONS

The panel was unanimous in noting that none of the proposed water monitoring systems as presented met the needs in all key areas of detection. In particular, some systems did an adequate job detecting organics but lacked capability to detect inorganic compounds. Others had the opposite bias, doing a reasonable job for detecting inorganics but falling far short for organic compounds.

After reviewing the scores, a majority of the panel members felt the scoring and weighting system was flawed. It rewarded those concepts that were less complex, even though they had not been demonstrated to measure all the parameters of interest. On the other hand, the systems that attempted to measure all the required parameters appeared to have been unduly punished due to the increased complexity needed to accomplish that task.

Concerning integration of monitoring systems, the panel unanimously agreed there was little to be gained by integrating air and water quality monitors into a single package. Although it might be possible to combine common analysis systems, the cost would probably be higher than for separate packages. The panel agreed that there was no real advantage for combining the organic and inorganic analyses for water quality contaminants into a single package. Although it might be possible to achieve a single package, the cost would likely be much higher than for separate packages. The panel felt that a broadly effective system could be developed most rapidly by subcontracting different modules to different vendors and by having NASA or one of the vendors act as system integrator.

Additional Conclusions

- The OSU porphyrin evanescent spectroscopy submittal had the highest scores in both the demonstrated and potential categories with its huge advantage of simplicity and low weight and power requirements. However, the panel noted this technology's unclear ability to handle samples in microgravity and analyze complex samples, making it a mid- to long-term option only.
- The JPL-Thorleaf proposal had the second highest score in the demonstrated category since it included a miniature GC/MS system that had already flown in space and had a wide dynamic range. It was ranked third in potential, however, as the system did not have the capability to

measure inorganic species and other required parameters.

- The Umpqua proposal received the third highest score in the demonstrated category since it had already developed prototype instruments that measured most of the priority 1 contaminants. It was ranked seventh in potential, however, as the system does not have the capability to measure most of the priority 2 and 3 compounds or to address unknowns.
- The Lynntech proposal had the fourth highest score in the demonstrated category due to its demonstrated reagentless TOC and IC technology. It received the second highest score in the potential category, however, due to innovative approaches to minimizing reagents and miniaturizing the components, even though monitoring of specific organic contaminants was not addressed.
- The Smiths Detection proposal had the fifth and fourth highest scores in the demonstrated and potential categories, respectively. Although it had a well-developed previously flown GC-IMS technology and its proposal addressed both organic and inorganic contaminants, the system was very complex and the electrode/voltammetry block for inorganics and the UV spectroscopy block for TOC were conceptual only.
- The Star Instruments proposal was ranked fifth in both the demonstrated and potential categories. Although the team had considerable NASA experience along with a well-developed TOC proposal and GC technology more simple than GC/MS or GC/IMS, its system appears to be large and complex. Monitoring of inorganics was not included, and the GC technology for organics was not as well-developed for space flight as other proposed GC/MS or GC-IMS systems.
- The OI Analytical proposal was ranked seventh and sixth in the demonstrated and potential categories, respectively. Although the concept included both organic and inorganic contaminants and they have well developed TOC and GC technology, its system was large and complex, its proposed gas liquid separator and IC technology for inorganics were conceptual only, and the team had little experience with space flight hardware.
- The Boeing team requested the deletion from this report of system description and all discussion related to the panel's evaluation of its proposal.
- Several panelists noted there were research groups and vendors developing water quality monitoring systems that did not respond to the RFI and they recommended that NASA not limit itself to those vendors that responded during its decision making process.
- For short-term (less than two years) monitoring of organics in water samples, there was no clear consensus on an approach that is better than the TOCA that is currently used on the Space Station. Two panelists indicated that none of the approaches presented could be developed in time for short-term implementation. The other panelists were divided with two recommendations for a reagentless TOCA, two recommendations for the Umpqua system (which includes a reagentless TOCA), two recommendations for a GC-IMS, and one recommendation for a GC/MS.
- For the proposals that included TOC measurement, two panelists each recommended the Lynntech and OI approaches.
- For specific organics monitoring over the intermediate term (two to five years), there were four panelist recommendations for a GC/MS, two recommendations for a GC-IMS, one

recommendation for the OI Analytical GC system, and two recommendations for the OSU system.

- When asked to choose between GC/MS or GC-IMS technology for the long-term (more than five years), six panelists recommended GC/MS while only two recommended GC-IMS. The most cited reason was GC/MS technology's capability to more easily handle unknowns.
- For short-term (less than two years) implementation of inorganics monitoring, the panel provided one recommendation each for the Lynntech and OI Analytical IC systems. One panelist was uncomfortable with all of the proposed concepts for short-term inorganics monitoring.
- For mid-term (two to five years) monitoring of inorganics, there were four recommendations for an IC, two recommendations for the electrode/voltammetry approaches, and two recommendations for the OSU approach.
- For long-term (more than five years) inorganics monitoring, there were three recommendations for the Lynntech reagentless IC concept and one recommendation for the OI IC concept. Three panelists noted that all the concepts presented for inorganics had weaknesses and further development in this area was necessary

APPENDIX 1: Individual Technology Assessment Metric Scoring Sheets

TECHNOLOGY ASSESSMENT METRIC

WATER QUALITY PANEL
SPACE STATION ENVIRONMENTAL MONITORING
REQUEST FOR INFORMATION
OCTOBER 2003

OI ANALYTICAL

This metric is a modified version of the tool used in the 1998 panel review of spacecraft air quality instrumentation.

Requirements Scale (except where noted)	
1	requirement not met, but meets 25-50% of requirement
2	requirement not met, but meets over 50% of requirement
3	requirement met
4	requirement exceeded

Parameter 1
Operation in Spacecraft Environment
Weighting factor= 1

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Temperature	65-85°F (18-29 °C)		4	4
Pressure	10.2-15.0 psia		3	4
Microgravity compatible	Absolute requirement	Samples may contain 20% gas by volume— issues with pump	* 1	* 3
Ability to perform in highly contaminated samples			2	4
Parameter Score			10	15

*Microgravity compatible: Inherent microgravity compatibility demonstrated= 4, Gas-liquid Separators or inherent compatibility included but not demonstrated= 3, Additional bubble removal from samples required= 2, Additional gas-liquid separators required= 1, Microgravity compatibility not addressed= 0

Parameter 2
Instrument Characteristics
Weighting factor= 1

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Analysis time	< 1 hr		1	3
Analytical cycle time	<1.5 hr		1	4
Mass	22 kg		1	4
Volume	$3.9 ft^3$ ($0.11 m^3$)		1	4
Power	<100 W/150W peak		1	3
Parameter Score			5	18

Parameter 3
System Characteristics
Weighting factor= 1 or 2

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Maturity including software (WF= 2)			See key* 2	See key* 4
Reagents (WF=2)			See key** 2	See key** 2
Environmental impact (WF= 1)	Contaminants not released to environment		See key*** 3	See key*** 3
Complexity (WF= 2)			See key**** 2	See key**** 3
Parameter Score			9	12

*Maturity: >TRL 8= 4, >TRL 6= 3, >TRL 4= 2, >TRL 2= 1, <TRL 2= 0

**Reagents: 0 reagents= 4, 1 reagent= 3, 2 reagents= 2, >2 resources= 1, exotic resources (i.e., LN2)= 0 (includes gases, other resources)

***Env.: No products released= 4, products released/not harmful= 3, Released products harmful to crew/systems= 0

****Complexity: < 3 modules= 4, < 5 modules= 3, <8 modules= 2, <10 modules= 1, >10 modules= 0

Parameter 4
Compounds
Weighting factor= 2

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
% Detectable Priority 1 parameters at specified limit			* 1	* 3
% Detectable Priority 2 & 3 parameters at specified limit			* 1	* 2
Quantitation range	0.1 to 100 times limit		1	2
Specificity in spacecraft waters			** 1	** 2
Accuracy (6 mo)			*** 1	*** 4
Precision (over 1 month operation)			*** 1	*** 4
Parameter Score			6	17

*% Compounds detected: >90%= 4, 75- 90%= 3, 50-75%= 2, 25-50%= 1, <25%= 0
**Specificity: Demonstrated on actual samples= 4, demonstrated on synthetic waters= 3, partial mixtures tested= 2, interferences addressed= 1, specificity not addressed= 0
***Accuracy:>90%= 4, >75%= 3, >50%= 2, Limited accuracy data= 1, no accuracy data= 0

Parameter 5:
Instrument Maintainability
Weighting factor= 1

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Calibration interval (quantitative purposes)	6 mo.		1	2
Maintenance interval: minor major	 every 6 mo. > 1 yr.		1	2
ORU's and Supplies	Every 6 months < 5 kg		See key* 1	See key* 3
Parameter Score			3	7

* ORU/Supplies: >6 mo/< 3 kg= 4, 6 mo/<5 kg= 3, 6 mo/> 5 kg= 2, <6 mo/< 5 kg= 1, <6 mo/>5 kg= 0

SMITHS DETECTION

This metric is a modified version of the tool used in the 1998 panel review of spacecraft air quality instrumentation.

Requirements Scale (except where noted)	
1	requirement not met, but meets 25-50% of requirement
2	requirement not met, but meets over 50% of requirement
3	requirement met
4	requirement exceeded

Parameter 1
Operation in Spacecraft Environment
Weighting factor= 1

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Temperature	65-85°F (18-29 °C)		4	4
Pressure	10.2-15.0 psia		4	4
Microgravity compatible	Absolute requirement	Samples may contain 20% gas by volume	* 1	* 3
Ability to perform in highly contaminated samples			1	3
Parameter Score			10	14

*Microgravity compatible: Inherent microgravity compatibility demonstrated= 4, Gas-liquid separators or inherent compatibility included but not demonstrated= 3, Additional bubble removal from samples required= 2, Additional gas-liquid separators required= 1, Microgravity compatibility not addressed= 0

Parameter 2
Instrument Characteristics
Weighting factor= 1

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Analysis time	< 1 hr		1	4
Analytical cycle time	<1.5 hr		1	4
Mass	22 kg	VOA= 40 kg	1	3
Volume	3.9ft3 (0.11m3)		1	3
Power	<100 W/150W peak		1	4
Parameter Score			5	18

Parameter 3
System Characteristics
Weighting factor= 1 or 2

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Maturity including software (WF= 2)		VOA= 4	See key* 2	See key* 4
Reagents (WF= 2)			See key** 3	See key** 3
Environmental impact (WF= 1)	Contaminants not released to env		See key*** 3	See key*** 3
Complexity (WF= 2)			See key**** 3	See key**** 3
Parameter Score			11	13

*Maturity: >TRL 8= 4, >TRL 6= 3, >TRL 4= 2, >TRL 2= 1, <TRL 2= 0

**Reagents: 0 reagents= 4, 1 reagent= 3, 2 reagents= 2, >2 resources= 1, exotic resources (i.e., LN2)= 0 (includes gases, other resources)

***Env.: No products released= 4, products released/not harmful= 3, Released products harmful to crew/systems= 0

****Complexity: < 3 modules= 4, <5 modules= 3, <8 modules= 2, <10 modules= 1, >10 modules= 0

Parameter 4:
Compounds
Weighting factor= 2

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
% Detectable Priority 1 parameters at specified limit		Did not address TOC	* 2	* 4
% Detectable Priority 2 & 3 parameters at specified limit			* 1	* 2
Quantitation range	0.1 to 100 times limit		1	4
Specificity in spacecraft waters			** 1	** 1
Accuracy (6 mo)			*** 1	*** 3
Precision (over one month operation)			*** 2	*** 3
Parameter Score			8	17

*% Compounds detected: >90% = 4, 75- 90%= 3, 50-75%= 2, 25-50%= 1, <25%= 0
**Specificity: Demonstrated on actual samples= 4, demonstrated on synthetic waters= 3, partial mixtures tested= 2, interferences addressed= 1, specificity not addressed= 0
***Accuracy: >90%= 4, >75%= 3, >50%= 2, Limited accuracy data= 1, no accuracy data= 0

Parameter 5
Instrument Maintainability
Weighting factor= 1

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Calibration interval (quantitative purposes)	6 mo.		1	4
Maintenance interval: minor major	 every 6 mo. > 1 yr.		1	4
ORU's and Supplies	Every 6 months < 5 kg		See key* 1	See key* 3
Parameter Score			3	11

* ORU/Supplies: > 6 mo/< 3 kg= 4, 6 mo/<5 kg= 3, 6 mo/> 5 kg= 2, < 6 mo/< 5 kg= 1, < 6 mo/> 5 kg= 0

JPL-THORLEAF

This metric is a modified version of the tool used in the 1998 panel review of spacecraft air quality instrumentation.

Requirements Scale (except where noted)	
1	requirement not met, but meets 25-50% of requirement
2	requirement not met, but meets over 50% of requirement
3	requirement met
4	requirement exceeded

Parameter 1
Operation in Spacecraft Environment
Weighting factor= 1

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Temperature	65-85°F (18-29 °C)		4	4
Pressure	10.2-15.0 psia		4	4
Microgravity compatible	Absolute requirement	Samples may contain 20% gas by volume	* 3	* 4
Ability to perform in highly contaminated samples			1	3
Parameter Score			12	15

*Microgravity compatible: Inherent microgravity compatibility demonstrated= 4, Gas-liquid Separators required or inherent compatibility included but not demonstrated= 3, Additional bubble removal from samples required= 2, Additional gas-liquid separators required= 1, Microgravity compatibility not addressed= 0

Parameter 2
Instrument Characteristics
Weighting factor= 1

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Analysis time	< 1 hr		1	4
Analytical cycle time	<1.5 hr		1	4
Mass	22 kg		4	4
Volume	3.9ft^3 (0.11m^3)		4	4
Power	<100 W/150W peak		2	4
Parameter Score			12	20

Parameter 3
System Characteristics
Weighting factor= 1 or 2

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Maturity including software (WF= 2)			See key* 3	See key* 4
Reagents (WF=2)		Internal standards?	See key** 3	See key** 3
Environmental impact (WF= 1)	Contaminants not released to environment	Location of carrier gas vents?	See key*** 3	See key*** 4
Complexity (WF= 2)			See key**** 2	See key**** 3
Parameter Score			11	14

*Maturity: >TRL 8= 4, >TRL 6= 3, >TRL 4= 2, >TRL 2= 1, <TRL 2= 0

**Reagents: 0 reagents= 4, 1 reagent= 3, 2 reagents= 2, >2 resources = 1, exotic resources (i.e., LN2)= 0 (includes gases, other resources)

***Env.: No products released= 4, products released/not harmful= 3, Released products harmful to crew/systems= 0

****Complexity: < 3 modules= 4, < 5 modules= 3, <8 modules= 2, <10 modules= 1, >10 modules= 0

Parameter 4
Compounds
Weighting factor= 2

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
% Detectable Priority 1 parameters at specified limit		Lack of inorganic detection	* 1	* 1
% Detectable Priority 2 & 3 parameters at specified limit			* 1	* 1
Quantitation range	0.1 to 100 times limit		3	4
Specificity in spacecraft waters		Identification – ok Quantification ?	** 2	** 3
Accuracy (6 mo)			*** 1	*** 3
Precision (over 1 month operation)			*** 1	*** 3
Parameter Score			9	15

*% Compounds detected: >90% = 4, 75-90%= 3, 50-75%= 2, 25-50%= 1, <25%= 0

**Specificity: Demonstrated on actual samples= 4, demonstrated on synthetic waters= 3, partial mixtures tested= 2, interferences addressed= 1, specificity not addressed= 0

***Accuracy: >90%= 4, >75%= 3, >50%= 2, Limited accuracy data= 1, no accuracy data= 0

Parameter 5
Instrument Maintainability
Weighting factor= 1

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Calibration interval (quantitative purposes)	6 mo.	O_2, N_2, H_2O, BTEX	4	4
Maintenance interval: minor major	 every 6 mo. > 1 yr.		4	4
ORU's and Supplies	Every 6 months < 5 kg		See key* 4	See key* 4
Parameter Score			12	12

* ORU/Supplies: > 6 mo/< 3 kg= 4, 6 mo/<5 kg= 3, 6 mo/> 5 kg= 2, < 6 mo/< 5 kg= 1, < 6 mo/> 5 kg= 0

STAR INSTRUMENTS

This metric is a modified version of the tool used in the 1998 panel review of spacecraft air quality instrumentation.

Requirements Scale (except where noted)	
1	requirement not met, but meets 25-50% of requirement
2	requirement not met, but meets over 50% of requirement
3	requirement met
4	requirement exceeded

Parameter 1
Operation in Spacecraft Environment
Weighting factor= 1

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Temperature	65-85°F (18-29 °C)		4	4
Pressure	10.2-15.0 psia		3	4
Microgravity compatible	Absolute requirement	Samples may contain 20% gas by volume	* 3	* 4
Ability to perform in highly contaminated samples			1	4
Parameter Score			11	16

*Microgravity compatible: Inherent microgravity compatibility demonstrated= 4, Gas-liquid separators or inherent compatibility included but not demonstrated= 3, Additional bubble removal from samples required= 2, Additional gas-liquid separators required= 1, Microgravity compatibility not addressed= 0

Parameter 2
Instrument Characteristics
Weighting factor= 1

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Analysis time	< 1 hr	All for GC/MS component	3	4
Analytical cycle time	<1.5 hr	All for GC/MS component	3	4
Mass	22 kg	All for GC/MS component	1	3
Volume	$3.9ft^3$ ($0.11m^3$)	All for GC/MS component	1	3
Power	<100 W/150W peak	All for GC/MS component	1	3
Parameter Score			9	17

Parameter 3
System Characteristics
Weighting factor= 1 or 2

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Maturity including software (WF= 2)			See key* 2	See key* 4
Reagents (WF=2)			See key** 2	See key** 2
Environmental impact (WF= 1)	Contaminants not released to environment		See key*** 2	See key*** 3
Complexity (WF= 2)			See key**** 2	See key**** 3
Parameter Score			8	12

*Maturity: >TRL 8= 4, >TRL 6= 3, >TRL 4= 2, >TRL 2= 1, <TRL 2= 0
**Reagents: 0 reagents= 4, 1 reagent= 3, 2 reagents= 2, >2 resources = 1, exotic resources (i.e., LN2)= 0 (includes gases, other resources)
***Env.: No products released= 4, products released/not harmful= 3, Released products harmful to crew/systems= 0
****Complexity: < 3 modules= 4, < 5 modules= 3, <8 modules= 2, <10 modules= 1, >10 modules= 0

Parameter 4
Compounds
Weighting factor= 2

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
% Detectable Priority 1 parameters at specified limit		Inorganics are a problem as proposed.	* 1	* 2
% Detectable Priority 2 & 3 parameters at specified limit			* 1	* 2
Quantitation range	0.1 to 100 times limit		1	3
Specificity in spacecraft waters			** 1	** 3
Accuracy (6 mo)			*** 1	*** 3
Precision (over one month operation)			*** 3	*** 4
Parameter Score			8	17

*% Compounds detected: >90% = 4, 75-90%= 3, 50-75%= 2, 25-50%= 1, <25%= 0
**Specificity: Demonstrated on actual samples= 4, demonstrated on synthetic waters= 3, partial mixtures tested= 2, interferences addressed= 1, specificity not addressed= 0
***Accuracy: >90%= 4, >75%= 3, >50%= 2, Limited accuracy data= 1, no accuracy data= 0

Parameter 5
Instrument Maintainability
Weighting factor= 1

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Calibration interval (quantitative purposes)	6 mo.	Inorganics problem	1	3
Maintenance interval: minor major	 every 6 mo. > 1 yr.		1	3
ORU's and Supplies	Every 6 months < 5 kg		See key* 1	See key* 4
Parameter Score			3	10

* ORU/Supplies: > 6 mo/< 3 kg= 4, 6 mo/<5 kg= 3, 6 mo/> 5 kg= 2, < 6 mo/< 5 kg= 1, < 6 mo/> 5 kg= 0

UMPQUA

This metric is a modified version of the tool used in the 1998 panel review of spacecraft air quality instrumentation.

Requirements Scale (except where noted)	
1	requirement not met, but meets 25-50% of requirement
2	requirement not met, but meets over 50% of requirement
3	requirement met
4	requirement exceeded

Parameter 1
Operation in Spacecraft Environment
Weighting factor= 1

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Temperature	65-85°F (18-29 °C)		4	4
Pressure	10.2-15.0 psia		4	4
Microgravity compatible	Absolute requirement	Samples may contain 20% gas by volume	* 1	* 4
Ability to perform in highly contaminated samples		Possible interference across membranes; Integrity of membranes?	2	2
Parameter Score			11	14

*Microgravity compatible: Inherent microgravity compatibility demonstrated= 4, Gas-liquid separators or inherent compatibility included but not demonstrated= 3, Additional bubble removal from samples required= 2, Additional gas-liquid separators required= 1, Microgravity compatibility not addressed= 0

Parameter 2
Instrument Characteristics
Weighting factor= 1

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Analysis time	< 1 hr		4	4
Analytical cycle time	<1.5 hr	Calibration time?	3	4
Mass	22 kg	Too heavy now	1	4
Volume	3.9ft^3 (0.11m^3)	Too large now	1	4
Power	<100 W/150W peak	Unclear if can be met	1	3
Parameter Score			10	19

Parameter 3
System Characteristics
Weighting factor= 1 or 2

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Maturity including software (WF=2)			See key* 2	See key* 4
Reagents (WF=2)			See key** 1	See key** 1
Environmental impact (WF=1)	Contaminants not released to environment	Wastewater released needs to be non-hazardous.	See key*** 2	See key*** 3
Complexity (WF=2)		7 modules estimated	See key**** 1	See key**** 2
Parameter Score			6	10

*Maturity: >TRL 8= 4, >TRL 6= 3, >TRL 4= 2, >TRL 2= 1, <TRL 2= 0
**Reagents: 0 reagents= 4, 1 reagent= 3, 2 reagents= 2, >2 resources = 1, exotic resources (i.e., LN2)= 0 (includes gases, other resources)
***Env.: No products released= 4, products released/not harmful= 3, Released products harmful to crew/systems= 0
****Complexity: < 3 modules= 4, < 5 modules= 3, <8 modules= 2, <10 modules= 1, >10 modules= 0

Parameter 4
Compounds
Weighting factor= 2

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
% Detectable Priority 1 parameters at specified limit			* 2	* 2
% Detectable Priority 2 & 3 parameters at specified limit			* 0	* 0
Quantitation range	0.1 to 100 times limit	Only two powers of 10 demonstrated	3	4
Specificity in spacecraft waters		Specific acids and alcohols?	** 3	** 3
Accuracy (6 mo)			*** 4	*** 4
Precision (over 1 month operation)		Repeatability not demonstrated	*** 3	*** 4
Parameter Score			15	17

*% Compounds detected: >90% = 4, 75- 90%= 3, 50-75%= 2, 25-50%= 1, <25%= 0
**Specificity: Demonstrated on actual samples= 4, demonstrated on synthetic waters= 3, partial mixtures tested= 2, interferences addressed= 1, specificity not addressed= 0
***Accuracy: >90%= 4, >75%= 3, >50%= 2, Limited accuracy data= 1, no accuracy data= 0

Parameter 5
Instrument Maintainability
Weighting factor= 1

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Calibration interval (quantitative purposes)	6 mo.	Non-linear curves; Needs more than 1 standard; Interval < 6 mo.	1	2
Maintenance interval: minor major	 every 6 mo. > 1 yr.	Not clear if can be met	1	3
ORU's and Supplies	Every 6 months < 5 kg	Not clear if can be met	See key* 1	See key* 3
Parameter Score			3	8

* ORU/Supplies: > 6 mo/< 3 kg= 4, 6 mo/<5 kg= 3, 6 mo/> 5 kg= 2, < 6 mo/<5 kg= 1, < 6 mo/>5 kg= 0

OKLAHOMA STATE UNIVERSITY

This metric is a modified version of the tool used in the
1998 panel review of spacecraft air quality instrumentation.

Requirements Scale (except where noted)	
1	requirement not met, but meets 25-50% of requirement
2	requirement not met, but meets over 50% of requirement
3	requirement met
4	requirement exceeded

Parameter 1
Operation in Spacecraft Environment
Weighting factor= 1

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Temperature	65-85°F (18-29 °C)		4	4
Pressure	10.2-15.0 psia		4	4
Microgravity compatible	Absolute requirement	Samples may contain 20% gas by volume	* 1	* 4
Ability to perform in highly contaminated samples		Unclear if will work with mixtures	1	2
Parameter Score			10	14

*Microgravity compatible: Inherent microgravity compatibility demonstrated= 4, Gas-liquid separators or inherent compatibility included but not demonstrated= 3, Additional bubble removal from samples required= 2, Additional gas-liquid separators required= 1, Microgravity compatibility not addressed= 0

Parameter 2
Instrument Characteristics
Weighting factor= 1

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Analysis time	< 1 hr		4	4
Analytical cycle time	<1.5 hr		4	4
Mass	22 kg		4	4
Volume	$3.9ft^3$ ($0.11m^3$)		4	4
Power	<100 W/150W peak		4	4
Parameter Score			20	20

Parameter 3
System Characteristics
Weighting factor= 1 or 2

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Maturity including software (WF=2)		Water sampling not addressed	See key* 1	See key* 4
Reagents (WF=2)			See key** 4	See key** 4
Environmental impact (WF=1)	Contaminants not released to environment	Waste not addressed yet	See key*** 3	See key*** 4
Complexity (WF= 2)		Sampling module?	See key**** 3	See key**** 4
Parameter Score			11	16

*Maturity: >TRL 8= 4, >TRL 6= 3, >TRL 4= 2, >TRL 2= 1, <TRL 2= 0
**Reagents: 0 reagents= 4, 1 reagent= 3, 2 reagents= 2, >2 resources = 1, exotic resources (i.e., LN2)= 0 (includes gases, other resources)
***Env.: No products released= 4, products released/not harmful= 3, Released products harmful to crew/systems= 0
****Complexity: < 3 modules= 4, < 5 modules= 3, <8 modules= 2, <10 modules= 1, >10 modules= 0

Parameter 4
Compounds
Weighting factor= 2

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
% Detectable Priority 1 parameters at specified limit		Can not measure TOC and conductivity	* 2	* 3
% Detectable Priority 2 & 3 parameters at specified limit		Unclear if can measure higher MW compounds	* 1	* 2
Quantitation range	0.1 to 100 times limit	Unclear if 3 orders of magnitude	1	4
Specificity in spacecraft waters		Effect of ionic strength?	** 1	** 2
Accuracy (6 mo)		Effect of mixtures?	*** 1	*** 3
Precision (over 1 month operation)			*** 4	*** 4
Parameter Score			10	18

*% Compounds detected: >90% = 4, 75-90%= 3, 50-75%= 2, 25-50%= 1, <25%= 0
**Specificity: Demonstrated on actual samples= 4, demonstrated on synthetic waters= 3, partial mixtures tested= 2, interferences addressed= 1, specificity not addressed= 0
***Accuracy: >90%= 4, >75%= 3, >50%= 2, Limited accuracy data= 1, no accuracy data= 0

Parameter 5
Instrument Maintainability
Weighting factor= 1

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Calibration interval (quantitative purposes)	6 mo.	Not demonstrated for all compounds	2	4
Maintenance interval: minor major	 every 6 mo. > 1 yr.		4	4
ORU's and Supplies	Every 6 months < 5 kg		See key* 4	See key* 4
Parameter Score			10	12

- * ORU/Supplies: > 6 mo/< 3 kg= 4, 6 mo/<5 kg= 3, 6 mo/> 5 kg= 2, < 6 mo/< 5 kg= 1, < 6 mo/> 5 kg= 0

LYNNTECH, INC.

This metric is a modified version of the tool used in the 1998 panel review of spacecraft air quality instrumentation.

Requirements Scale (except where noted)	
1	requirement not met, but meets 25-50% of requirement
2	requirement not met, but meets over 50% of requirement
3	requirement met
4	requirement exceeded

Parameter 1
Operation in Spacecraft Environment
Weighting factor= 1

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Temperature	65-85°F (18-29 °C)		4	4
Pressure	10.2-15.0 psia		4	4
Microgravity compatible	Absolute requirement	Samples may contain 20% gas by volume	* 1	* 4
Ability to perform in highly contaminated samples		Carbonate peak? High formate peak?	1	3
Parameter Score			10	15

*Microgravity compatible: Inherent microgravity compatibility demonstrated= 4, Gas-liquid separators or inherent compatibility included but not demonstrated= 3, Additional bubble removal from samples required= 2, Additional gas-liquid separators required= 1, Microgravity compatibility not addressed= 0

Parameter 2:
Instrument Characteristics
Weighting factor= 1

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Analysis time	< 1 hr		4	4
Analytical cycle time	<1.5 hr		4	4
Mass	22 kg		3	4
Volume	$3.9 ft^3$ ($0.11 m^3$)		3	4
Power	<100 W/150W peak		4	4
Parameter Score			18	20

Parameter 3
System Characteristics
Weighting factor= 1 or 2

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Maturity including software (WF= 2)			See key* 2	See key* 4
Reagents (WF=2)		Water and salt	See key** 2	See key** 2
Environmental impact (WF= 1)	Contaminants not released to environment	Brine solution	See key*** 3	See key*** 3
Complexity (WF= 2)		Estimate 3 to 7 modules	See key**** 2	See key**** 2
Parameter Score			9	11

*Maturity: >TRL 8= 4, >TRL 6= 3, >TRL 4= 2, >TRL 2= 1, <TRL 2= 0
**Reagents: 0 reagents= 4, 1 reagent= 3, 2 reagents= 2, >2 resources = 1, exotic resources (i.e., LN2)= 0 (includes gases, other resources)
***Env.: No products released= 4, products released/not harmful= 3, Released products harmful to crew/systems= 0
****Complexity: < 3 modules= 4, < 5 modules= 3, <8 modules= 2, <10 modules= 1, >10 modules= 0

Parameter 4
Compounds
Weighting factor= 2

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
% Detectable Priority 1 parameters at specified limit		Can not measure specific organics, pH, and conductivity	* 2	* 2
% Detectable Priority 2 & 3 parameters at specified limit		23/47, no specific organics	* 1	* 1
Quantitation range	0.1 to 100 times limit	No calibration plots	0	4
Specificity in spacecraft waters			** 1	** 4
Accuracy (6 mo)		No data/calibration curves	*** 0	*** 4
Precision (over 1 month operation)		Only minimal repeatability data	*** 1	*** 4
Parameter Score			5	19

*% Compounds detected: >90% = 4, 75-90%= 3, 50-75%= 2, 25-50%= 1, <25%= 0
**Specificity: Demonstrated on actual samples= 4, demonstrated on synthetic waters= 3, partial mixtures tested= 2, interferences addressed= 1, specificity not addressed= 0
***Accuracy: >90%= 4, >75%= 3, >50%= 2, Limited accuracy data= 1, no accuracy data= 0

Parameter 5
Instrument Maintainability
Weighting factor= 1

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Calibration interval (quantitative purposes)	6 mo.	Suggested monthly calibration necessary	1	3
Maintenance interval: minor major	 every 6 mo. > 1 yr.	In breadboard phase	1	4
ORU's and Supplies	Every 6 months < 5 kg	In breadboard phase	See key* 1	See key* 4
Parameter Score			3	11

* ORU/Supplies: > 6 mo/< 3 kg= 4, 6 mo/<5 kg= 3, 6 mo/> 5 kg= 2, < 6 mo/< 5 kg= 1, < 6 mo/> 5 kg= 0

APPENDIX 2: Presenter/Vendor Responses to Panel Scoring Sheet

Star Instruments Comments

We will submit comments but we only received a partial score tabulation from you (did not receive the TOCA portion). The confusion probably stems from our dual submittals:1) as a team member of the Boeing team, we covered the TOCA presentation portion by Jeff Jeffers of Star and 2) as an independent submitter, we covered all the air and water portions, as requested. I mentioned in the opening remarks that we would not repeat the same presentation we made with the Boeing team, however it was an integral part of our submittal. Dr. Overton presented a system which had dual usage for some water speciation and the air monitoring. While we will be providing detailed comments, I do recall a question directed to Dr. Overton regarding handling of the gaseous portion of the water samples, whereby he responded that it was for the other team members to decide. Jeff Jeffers had discussed membrane techniques in the Star portion of Boeing's presentation (which were developed by us on a previous contract) that would be used in the water sampling for that purpose, but Dr. Overton was restricted from the Boeing meeting due to other proprietary subjects covered.

Parameter 1: Operation in Spacecraft Environments
Under Demonstrated: Ability to perform in highly contaminated samples: Our score of “1” does not recognize the fact that because of the clean out cycle built into the microFAST GC and its very fast analytical cycle, contaminated samples can be easily and rapidly cleaned out of the analytical system. This instrument is readily adaptable to analyzing contaminated samples and can be rapidly purged of contaminants prior to subsequent trace analyses.

Parameter 2: Instrument Characteristics
A score of “1” for demonstrated mass, volume, and power does not seem to recognize the fact that the current instrument, without its plastic box, weighs <10lbs, has a volume of <0.8 cu ft, and typically uses 100 watts of power for VOCs. A score of “4” for each of these categories may be considered.

Parameter 3: System Characteristics
The only reagents needed are the carrier gas (nitrogen) and detector make-up gas (argon and argon/methane)

Parameter 4: Compounds
All priority 1 compounds can be detected by GC methods: could be ranked 4
All priority 2 compounds can be detected by GC methods: could be ranked 4
All priority 3 compounds can be detected by GC methods: could be ranked 4

All compounds can be detected within the detection limit ranges using fast GC analysis of the sample at several different levels of concentration. This is feasible because of the speed of analysis of the microFAST GC and the fact it has a built-in solid trap for concentrating analytes prior to injection onto the GC columns. With weekly calibration using appropriate standard compounds, qualitative and quantitative accuracies should be >90% for target compounds.

Parameter 5: Instrument Maintainability
Ranking seems reasonable

Oklahoma State University Comments (via email, Harmon to Schultz, January 2004)

Thank you for the opportunity to present our water quality detection technology in October 2003. I am in receipt of the assessment metric and feel that, overall, the assessment is fair and valid. I would like to briefly address a few points, however.

In Parameter1, while we have not measured mixtures of interest to the Space Station, we welcome the opportunity to do so if test mixtures could be provided to us. Microgravity is a major concern; to be honest, I would welcome an opportunity to see the existing or proposed water system so I can evaluate if, where, etc. the sensor surface (need only be a ¼" diameter spot or so) could be placed in the unit or an existing separator. If you recall, we need only the ability to run an optical fiber (we demonstrated a large bundle) or a glass/plastic rod to our sensor surface.

In Parameter 3, under "Complexity" and "Maturity", we do not use a "sampling module" since we need only place the surface in the medium (tank or stream); real-time monitoring without additional modules and associated controls, etc. is possible.

In Parameter 3, we do not generate any waste other than the spent/used reactor surface; liquid that has flowed past the surface is not contaminated and is not a waste product. The surface indicator porphyrins are covalently bound and do not come off into the medium by exposure to salt, high ionic strength, alcohols, solvents; at pH extremes or very high temps (the water would be boiling), some of the surface may be released.

Under Parameter 4, I have several comments. In the "Accuracy (6 mo)" category, the comment is made "Effect of Mixtures"; I do not understand the relevance of mixtures to accuracy over 6 months.

Since hydrophobic bonds and Van der Waals forces drive the interaction of the analytes to our surfaces, the presence of salts (high ionic strength) does not affect our sensor performance. If our interactions were ionic in nature, this would be a concern, but this is not the case.

"Quantitation Range" of three orders of magnitude is indeed possible for some analytes, but we have not tested all, as the score indicates. Because of our work with weapons of mass destruction, we have worked to detect as low of a concentration as possible for all analytes. The requirement to detect at 100x the limit is definitely different, but not impossible. For higher detection levels, we increase the amount of indicator fixed on each surface to increase the dynamic range of the sensor.

Also, we do not detect TOC or conductivity, as noted. In our work, we have not entered those areas where we felt we could not make an impact or improve on a technology. Also, we do not see any one instrument as being able to test all analytes equally well.

As I said, in general I concur with the ratings at this time. If we had an opportunity to address our "shortcomings" in the lab with directed research efforts, I am confident that many of these areas can be adequately addressed.

Again, I thank you for the opportunity to present our work to such an impressive review panel.

JPL-Thorleaf Comments using Technology Assessment Metric format
(JPL-Thorleaf comments in **bold**)

Parameter 2
Instrument Characteristics
Weighting factor= 1

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Analysis time	< 1 hr	**Our analysis time at the moment (the time between introducing the sample and obtaining an identification and concentration) is already about 15 minutes.**	1 3	4
Analytical cycle time	<1.5 hr	**After a round of any benchmarking and cleaning, we would be ready for another sample in 20 min or less.**	1 3	4
Mass	22 kg		4	4
Volume	1.2ft^3 (0.034m^3)		4	4
Power	<100 W/150W peak	**We will certainly meet this requirement for the combined air and water-sampling modules, and with the planned, small 60 liter/sec turbo-molecular pump on the systems.**	2	4
Total Score Parameter Score			12 16	20

Parameter 3
System Characteristics
Weighting factor= 1 or 2

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
Maturity including software (WF= 2)			See key* 3	See key* 4
Reagents (WF= 2)		INTERNAL STANDARDS? **We will be using inert internal standard (e.g., rare gases). The types and amounts are small.**	See key** 3	See key** 3
Environmental impact (WF= 1)	Contaminants not released to environment	CARRIER GAS VENTS WHERE? **Carrier gas vents to the Space Station Vacuum Resource System (VRS) (if helium); or to the cabin itself (if nitrogen). The flows are very low, in the range ml/min, and will not impact crew safety. If desired, the nitrogen can also be released to the VRS.**	See key*** 3 4	See key*** 4
Complexity (WF= 2)		**While there are a number of modules (the preconcentrator, GC, mass spectrometer, electronics) many of these items are doing double duty in both air and water sampling. Hence there's an innate simplification here.**	See key**** 2 3	See key**** 3
Total Score Parameter Score			11 13	14

*Maturity: >TRL 8= 4, >TRL 6= 3, >TRL 4= 2, >TRL 2= 1, <TRL 2= 0
**Reagents: 0 reagents= 4, 1 reagent= 3, 2 reagents= 2, >2 resources = 1, exotic resources (i.e., LN2)= 0 (includes gases, other resources)
***Env.: No products released= 4, products released/not harmful= 3, Released products harmful to crew/systems= 0
****Complexity: < 3 modules= 4, < 5 modules= 3, <8 modules= 2, <10 modules= 1, >10 modules= 0

Parameter 4
Compounds
Weighting factor= 2

Attribute	Mission Requirement	System Performance	Score (0-4) Demonstrated	Score (0-4) Potential
% Detectable Priority 1 parameters at specified limit		LACK OF INORGANIC DETECTION We would be able to detect four out of the six requirements (TOC and formate not detected). This is 67%, or a potential of 2.	* 1	* 1 2
% Detectable Priority 2 & 3 parameters at specified limit		In Priority 2, we would be able to detect four and, possibly, five (formaldehyde) out of the seven (the ionic acetates and propionic acid not detected). This is 57% (4/7), or a potential of 2. In Priority 3, we would be able to detect 15 out of the 16 listed (ionic acids are not detected). This is 93%, or a potential of 4.	* 1	* 1 2
Quantitation range	0.1 to 100 times limit		3	4
Specificity in spacecraft waters		IDENTIFICATION – OK. QUANTIFICATION ? We have already demonstrated the same quantification capability in the water module as we have in the air module.	** 2 3	** 3
Accuracy (6 mo)		For both accuracy and precision, we should be able to do as well as the commercial, ground-based GCMS systems.	*** 1	*** 3 4
Precision (over 1 month operation)		See note on "Accuracy" above.	*** 1	*** 3 4
Total Score Parameter Score			9 10	15 19

*% Compounds detected: >90% = 4, 75- 90%= 3, 50-75%= 2, 25-50%= 1, <25%= 0
**Specificity: Demonstrated on actual samples= 4, demonstrated on synthetic waters= 3, partial mixtures tested= 2, interferences addressed= 1, specificity not addressed= 0
*** Accuracy: >90%= 4, >75%= 3, >50%= 2, Limited accuracy data= 1, no accuracy data= 0

Additional Notes from JPL-Thorleaf:

Two items worthy of mention are:

The miniature GC/MS system is doing double duty by providing a means for VOC sampling of the water system and the cabin air. The unit could also augment or replace the major constituents analyzer.

As with any other GCMS system, the present miniature system is capable of identifying unanticipated compounds (provided their fragmentation pattern exists in our large, onboard library of molecules).

Smiths Detection Comments (via email, Brokenshire to Schultz, January 2004)

Generally we felt that the assessment was very fair, but that there were two items which we believe to have been judged rather harshly.

The first is under Parameter 4 - System Performance where it states "DO NOT ADDRESS TOC". The second is under Specificity in spacecraft waters where a score of only “1” was awarded for Potential.

We look forward to receiving the draft report later this month and we also await the results of the air panel's deliberations.